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Effect of Reverse Engineering Pedagogy on Students' Learning Performance, Cultural Heritage Literacy, and Creativity in a Paper Sculpture C-STEAM Course

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Abstract: *The traditional cultures around the world not only symbolize the spirit and soul of different countries, but also provide the most essential resources for education. This study examined the effect of reverse engineering pedagogy (REP) and forward project pedagogy (FPP) on students' cultural heritage literacy and creativity in a cultural-oriented STEAM course (C-STEAM). A total of 128 undergraduate students from a major university in China participated in a paper sculpture C-STEAM project, and were randomly divided into two groups: the treatment group (with 64 students) that adopted REP, and the control group (with 64 students) that adopted FPP. Results indicated that both FPP and REP promoted students' cultural heritage literacy and creativity. Although students' risk-taking and curiosity in the FPP group outperformed those in the REP group, students in the REP group achieved significantly better learning performance and higher levels of cultural understanding than those in the FPP group. In particular, the REP group wisely established a close relationship between cultural heritage and creativity by presenting complete cultural works in advance. This discovery has important research significance and practical value, by enlightening us to reflect deeply on the effect of REP when implementing the C-STEAM curriculum, and to identify the potential linkage between cultural inheritance and creativity.*

Keywords: C-STEAM education, reverse engineering pedagogy, paper sculpture course, cultural inheritance, creativity

1. Introduction

Every country has its own diverse and representative culture, which not only records the development and change of the nation, but also carries the wisdom and spirit of a race. Tenon and mortise joints of ancient Egypt, citterns of Austria, opera in Italy, Bunraku in Japan (a Japanese form of puppet theatre), and Scottish bagpipes are just a few examples. All of them uncover wisdom condensed by human beings in different ages of human history, which is passed down from generation to generation. Cultural diversity symbolizes the spirit and soul of nations and serves as a fundamental educational resource. To protect traditional civilization, which has been regarded as sweat equity, is deemed necessary (Kim & Chae, 2016). Nevertheless, with the trend of new scientific technology bringing convenience to people's lives, studies, and work, multiculturalism is born and has flooded people's daily routines, leading to conflict with traditional culture. Many traditional cultures are confronted with the predicament that there is nobody to inherit them, and so the development of national culture is becoming bogged down.

STEAM education emphasizes the integration of Science, Technology, Engineering, Arts, and Mathematics, and targets cultivating interdisciplinary talents (Conradty & Bogner, 2020; Yakman & Lee, 2012), where the letter "A" of "STEAM" contributes greatly to promoting students' humane accomplishments and creativity (Park et al., 2018). STEAM education has been reported to be effective in terms of academic learning achievements and higher-order thinking skills (Wahono et al., 2020) and has evoked various educational reforms in different countries (Conradty & Bogner, 2020; Herro & Quigley, 2016). For instance, the UK government advocated a policy agenda to integrate the four subjects into STEM (Conradty & Bogner, 2018). In Korea, STEAM education is known as "convergence talent education" (Park et al., 2012) and emphasizes the cultivation of students' creativity and imagination (Jho et al., 2016; Kim & Chae, 2016).

In recent years, STEAM education has been reconstructed locally when introduced in each country, providing possibilities for integrating cultural heritage. Zhan et al. (2020a, 2021) introduced a concept model of C-STEAM where C stood for culture, aiming at inheriting and innovating the traditional culture, and highlighted the fusion of inherent multidisciplinary and thinking styles. C-STEAM suggests that students could apply multidisciplinary knowledge in deep exploration within the context of inheriting outstanding culture, and enhance the acceptance of and pride in traditional culture, contributing to promoting students' patriotism and national confidence. The C-STEAM concept has attracted a range of programs aimed at the understanding and innovation of Chinese traditional culture with local unique features. For example, Li (2019) designed a C-STEAM course that integrated Chinese medicine culture into a learning project that enabled students to develop scientific inquiry and social responsibility, thus embodying educational value.

Paper art culture stands out in various colorful traditional cultures for its specialty. The paper sculpture techniques of paper art culture have become major elements of some artistic works. Specifically, paper sculpture is a kind of aesthetic expression made by curving, flexing, and overlaying traditional printing paper. Three-dimensional curving appeared early as one style of paper sculpture, and then stereoscopic figures emerged in China after that. Nowadays, a growing number of colleges in China are paying attention to paper sculpture, regarding it as teaching content for art courses that can be presented at art festivals at schools or universities.

However, when implementing C-STEAM education, some students have reported the difficulty of making a cultural product “starting from scratch.” Some educators have tried the product-based pedagogy (Zhan et al., 2022) to cultivate students’ creative and innovative competency, which refers to a method of teaching and learning in which learners develop knowledge through designing, and completing projects (Choi et al., 2019). However, such forward project pedagogy (FPP) requires students to start from scratch until the entire project is completed, which necessitates both a strong student foundation and a long teaching period (Savery, 2015). Meanwhile, the Reverse Engineering Pedagogy (Zhong et al., 2020) has been implemented in Robotics education. Contrary to forward project-based learning that emphasizes the process from ideas to projects, RE (Reverse Engineering) is a process of reverse splitting and disassembling of products for improvement and redesign, which emphasizes understanding and overall grasping of projects, and has broad application prospects in engineering courses (Calderon, 2010; Zhong et al. 2020). Previous research claimed that reverse engineering pedagogy has many advantages in teaching, especially for stimulating independence of learning, and promoting the development of products and crafts (López et al., 2019).

This pedagogy is heavily weighted towards the materialization of learning outcomes and is also applicable to C-STEAM education. As promoted by Zhan et al. (2020, 2021), it is conducted to stimulate students to disassemble and recover in a reverse design of cultural products. It also helps students to dissect modern needs of traditional culture from the perspective of product usability, so that the technical elements could be adopted properly. They can generate a series of micro innovations to foster the heritage of creativity in traditional culture. Considering its advantages, worthwhile is to further explore how to effectively apply this kind of pedagogy in STEAM education.

To sum up, the purpose of this study is to examine the effect of reverse engineering pedagogy (REP) and forward project pedagogy (FPP) on students’ learning performance, cultural heritage literacy and creativity in a paper sculpture C-STEAM course. Learning performance, in this study, refers to the measurable outcomes of students’ engagement in the course, including their acquisition of knowledge, skills, and abilities related to paper sculpture. Cultural heritage literacy, on the other hand, encompasses a multifaceted understanding of traditional culture. It involves students’ ability to not only understand and appreciate the values and meanings embedded in cultural artifacts and practices but also actively engage in cultural recognition and practice (Phinney & Ong , 2007). Creativity pertains to students’ capacity to generate novel and useful ideas, solutions, or products in the context of the C-STEAM course, particularly as they relate to the innovative design and creation of paper sculptures. Aiming at introducing outstanding traditional culture into the campus, the current study could provide an example of merging STEAM education with traditional culture to integrate technology and humanity and to help students appreciate the humanistic value in the process of innovative design.

2. Literature review

2.1. Traditional Paper Sculpture

Paper Sculpture originated in the Han Dynasty in ancient China; it is also widely known

as Paper Carving or Paper Engraving. Paper art is a kind of aesthetic art form mainly made of traditional printing paper and finally formed through engraving, bending, and overlaying steps. Stereoscopic carving is one of the earliest artistic styles of paper sculpture, in which the artistic figures are made by hand knitting and tying paper as the main material, then shaping it using a knife. There are two kinds of stereoscopic carving (i.e., graphic paper sculpture and 3D paper sculpture). Graphic paper sculpture such as paper cuttings and rigid paper carving uses simple colored paper as the medium to produce a piercing sense by tailoring and engraving (Tang, 2019) 3D paper sculpture forms the plane paper into a 3D shape that combines the artistic beauty of painting and engraving through cutting, curving, and molding, producing a unique uneven effect when the light strikes.

As a kind of handmade work, the paper sculpture skill is normally taught in an aesthetics curriculum at schools or in art clubs, where students can have active access to different cultures (Tang, 2019). As reported by Long (2020), who implemented a paper sculpture course in a high school, students had a higher degree of innovative consciousness, thinking style of applying disciplinary knowledge, problem-solving skills, and sentiment of being artisans in the course. Previous studies demonstrated that origami folding art has inspired the potential for creative design and other skills (Megahed, 2017; Morrow & Morrow, 2011). Morrow and Morrow (2011) conducted a program called CORE (close observation and reverse engineering) for constructing origami models, which helped to foster students’ learning and problem-solving skills. According to Wales (2012), when students learned origami, their spatial cognition and communication skills were effectively generated (Cakmak et al., 2014).

2.2. C-STEAM Education

C-STEAM education aims to integrate cultural understanding into the localized STEAM education. The letter C stands for Culture, indicating the concept of inheriting traditional culture and implemented by multidisciplinary STEAM education (Zhan et al., 2020), emphasizing the output of innovative cultural products based on a cultural theme for fusion and exteriorization in technology and humanity (Zhan et al., 2021). In several studies, a series of C-STEAM courses that apply regional cultural materials have been developed. These include Wu et al.’s (2022) wooden arch bridge project that drew on the mortise and tenon construction culture, Zhan et al.’s (2021) dragon boat project which integrated Dragon Boat Festival culture, Huo et al.’s (2020) Cantonese slang cases based on Cantonese culture, and He et al.’s (2022) “Cultural Guangzhou” Sand Tray project which is related to the culture of the city of Guangzhou. Other studies have focused on how a C-STEAM project affects children’s positive psychological development (Guan & Zhan, 2021) and how Chinese medicine culture can improve students’ cultural identity and national confidence (Li, 2019). Additionally, some researchers in other countries have carried out programs similar to C-STEAM. For example, the Korean teachers developed a program on the traditional musical instrument “Danso” to help students develop their creativity and cultural heritage literacy and build up their understanding through exploring the beauty of traditional Korean culture (Kim & Chae, 2016).

In terms of active learning, activities where students develop tangible prototypes can be considered a process which is based on “learning-by-doing.” These activities usually provide students with the required technical assistance to transform their ideas into tangible prototypes (Juškevičienė et al., 2021). In addition, some scholars have suggested that the combination of STEAM education and VR-assisted experience courses can help improve students learning satisfaction and learning effect, and stimulate their learning motivation (Hsiao et. al., 2021). C-STEAM education emphasizes learning by doing and learning by playing (Zhan et al., 2020a). Thus, students' cultural inheriting and understanding may be enhanced through a project or serial activities. Elements such as arts, history, architecture, and festivals, all represent typical cultural backgrounds, cultural themes, and the manifestation of achievement, contributing to integrating liberal arts and science. The cultural value of arts can be reflected in creativity, aesthetic sensibilities and appreciation, higher spatial reasoning skills, and sensory awareness (Land, 2013). For instance, the paper sculpture C-STEAM education project contributes to the development of the "A" elements in STEAM education, holding special artistic educational value and cultural heritage value. In this sense, C-STEAM could be regarded as a carrier of culture that can activate the natural needs, social needs, and spiritual needs of local people. Participants have more opportunities to gain deeper insights into the history and cultural experience when they are participating in C-STEAM activities, which could enhance their identity and understanding of cultural elements, contributing to disseminating various outstanding traditional cultures.

2.3. Reverse engineering pedagogy (REP)

Reverse Engineering (RE) is a process of extracting information about a product from the product itself (Steven, 2008). It generally starts with a final product, followed by dissecting it to understand its functionality, design, and other useful information (Ali et al., 2013). Besides, Huang considered RE as a redesign process that maximizes the usage of current design principles and key technologies (Huang, 2000). It has been used in several domains such as mechanical engineering and computer science (Bertoni, 2019). For instance, it is regarded as a common design strategy in the industry (Curtis et al., 2011), and is considered to enhance engineers' adaptability, flexibility, innovative thinking, and risk-taking ability (Ali, 2005). Meanwhile, the design process of engineering has been considered as an effective teaching pedagogy (Lin et al. 2024; Otto and Wood, 1998; Zhong et al. 2020).

The "disassembly-analysis-assembly" (DAA) model is a typical REP model that enables students to practice in hands-on projects following three steps: disassemble, analyze, assemble (Calderon, 2010). It has been widely used in engineering education (Ogot et al., 2008). Students first observe and play with the existing products and explore the overall structure, and then they can take it apart and analyze its working functions in detail to recapture the abstract and top-level specifications of the original design. This process helps students understand the design rationale and tradeoffs from multiple angles through the final products or solutions (Calderon, 2010). Furthermore, Zhong et al. (2024) suggested a five-step deconstructive recovery experiment: experience and analysis, decomposition and restoration, redesign and micro-innovation, prototyping or re-engineering, and evaluation and reflection.

Besides, there are some REP applications in STEM education. For example, Liu et al. (2023) applied REP to STEM teaching activities in primary schools, provided an example of the use of REP in primary school robot education, and indicated that REP played a positive role in developing students' CT skills in STEM learning activities. Shooter (2008) conducted a research

project called "PaperPro" that allowed students to explore how a stapler works in different ways, and used product dissection and reverse engineering as the guiding principle to make suggestions for better designs. Many creative ideas were generated by this method. Another experiment was conducted by Zhong et al. (2020), who explored the effectiveness of reverse engineering pedagogy (REP) and forward project-based pedagogy (FPP) in K-12 robotics education. They found that students who learned through REP had higher performance in compatibility and creative self-efficacy than those who learned through FPP (Zhong et al., 2020). Moreover, Liu et al. (2019) provided reverse cases such as troubleshooting, reverse impeller, and so on in the instructional process of firing painted pottery, to cultivate students' competencies of cooperation, expression, creativity, and innovation.

As a pedagogy that adopts the concept of reverse engineering in the education context, the reverse engineering pedagogy (REP) has been used to promote students' learning experience (Pegna et al., 1998), design thinking(Ladachart et al., 2022), creativity (Liu et al., 2023), computational thinking skills (Liu et al., 2023), and problem-solving abilities (López et al., 2019). It also helps students more efficiently understand the scientific concepts and the given system with multidisciplinary complexity (López et al., 2019; Wood et al., 2001), and helps students realize the magnitude of using systems engineering methods properly. For instance, according to Grantham et al. (2013), students who engaged in dissection before the redesign exhibited higher creativity and better product functionality than those who did not. Lin et al. (2024) innovatively combined C-STEAM education with reverse engineering teaching, and verified the effectiveness of C-STEAM reverse engineering teaching mode on students ' creative thinking, cultural ability and engineering thinking. Besides, Liu et al. (2023) have verified that REP could develop students computational thinking skills better than the demonstration method.

Generally, existing research evidenced that REP holds certain educational potential. However, compared to forward project-based pedagogy (FPP), whether REP in C-STEAM Course can improve students ' Learning Performance, Cultural Heritage Literacy, and Creativity remains to be explored.

3. Research Questions and Hypotheses

This study aimed to answer the following research question, "Compared to forward project-based pedagogy (FPP), does reverse engineering pedagogy (REP) help to better cultivate students' learning performance, cultural heritage competence, and creativity in the paper sculpture C-STEAM course?" We were also curious about the linkage between students' cultural heritage competence and their creativity. Specifically, the following four hypotheses were proposed accordingly:

H1. REP outperforms FPP in learning performance in the learning process of paper sculpture techniques. This was proposed because it was reported that students in REP performed better in terms of capability and learning achievements in K-12 robotic education than those in FPP (Zhong et al., 2020), and some researchers suggested adopting REP in promoting students' understanding of complex systems (López et al., 2019; Pegna et al., 1998).

H2. Students in REP have a higher degree of cultural understanding and heritage competence than students in FPP. This was proposed because reverse engineering provided a complete cultural product at first, and students would have an integral impression and understanding before making the product (Kim & Chae, 2016). Therefore, it was hypothesized that REP would be more helpful for promoting cultural heritage literacy.

H3. REP is more helpful than FPP in promoting students' creativity. This was proposed according to Zhong et al.'s (2020) research indicated that students in REP performed better than FPP on creative self-efficacy in K-12 robotic education. Another example was the case of a firing-faience STEAM program reported by Liu (2019), in which students developed the capability of cooperation, expression, manufacturing, monitoring, and innovation through the reverse engineering process.

H4. Students with enhanced cultural heritage competence demonstrate higher levels of creativity and innovative thinking than those with limited cultural heritage knowledge. This was proposed according to Falavarjani et al.'s (2018) research that studied the impact of acculturation identification and acculturative stress on creativity among Iranian immigrants living in Malaysia. They investigated how patterns of heritage and mainstream cultural identification and acculturative stress explained how Iranians living in Malaysia demonstrated enhanced creativity in creative achievements and creative problem-solving.

4. Methodology

4.1. Participants

A total of 128 (52 male, 76 female) university students aged from 19 to 23 years old and majoring in educational technology, Chinese language and literature, English Education and Mathematics education from a major university in south China participated in the experiment. They were randomly assigned to a treatment group that adopted REP (64 students) and a control group that adopted FPP (64 students).

4.2. Measuring Instruments

Students learning performance is tested by a content examination comprising a set of single-choice questions, cloze tests, and short answer components. Among them, the single-choice question is a direct and clear question type. The cloze test is an indirect way of investigation, which requires students to fill in the blank part according to the context and existing knowledge. The short answer part pays more attention to students thinking and expression abilities. Through these different types of questions to more comprehensively and accurately assess the students mastery of the basic knowledge of paper and students practical ability. For example, the single-choice question, "Which dynasty did paper sculpture originate from?" evaluated students' knowledge of the history of Chinese paper sculpture. The Cloze test question, "The first western artworks of paper carving were made using papyrus and are called," evaluated students' understanding of the historical context of paper sculpture culture in Western countries. The short answer question, "How many kinds of platonic polyhedrons are there?" investigated students' knowledge of paper art.

Students' cultural understanding and inheritance literacy were evaluated using a scale adapted from Phinney and Ong (2007), with a Cronbach's alpha of .81 and a reliability of .74. (Huo et al., 2020). The scale was made up of 15 items consisting of three categories: cultural understanding, cultural recognition, and cultural practice, produced in the format of a 5-point Likert scale.

Students' creativity was measured by Williams' Creativity Scale, which comprised four dimensions (i.e., adventure, curiosity, imagination, and challenge). There was a total of 50 question items in the scale and the Cronbach's α values of this construct ranged between .801 and .809, indicating a high degree of reliability (Lin & Wang, 1997).

4.3. Intervention

In the FPP group, the teacher first introduced the basic knowledge and the application of 3D paper sculpture to students and elaborated the technological process and tools. Besides, the teacher guided students to explore the cultural connotations and characteristics of paper sculpture and analyzed its practical use to spark ideas. Then students could determine the way to design products with originality and innovation rationally and feasibly. The crucial point of this teaching activity was making and prototyping. Students determined the structure of the paper sculpture by designing and sketching the products, and then they needed to design and draw patterns of the paper sculpture; the teacher could provide some simple patterns for reference and then inspect the plans. The production and testing of their paper sculpture works were carried out in the next step. Students designed sketches, and then assembled the paper art light by engraving patterns and splicing the prepared components such as light-emitting diodes provided by the teacher. Once the products were completed, students needed to compare and summarize their works to check whether the paper art lights achieved their intended goals. The teacher would give positive credit to those groups who finished the program and help those who did not complete the project to search for the reasons for failure, and supply improvement suggestions based on identified problems. Finally, the teacher graded students' achievements in each group by filling out evaluation forms, which evaluated their works from four dimensions: integrity, practicability, innovation, and artistry.

In the REP group, students started by observing a physical product that was displayed by the teachers (see Figure 2). The product can be either a complete work or a faulty one. Then, students disassembled the product. Given the complete work, students should observe and perceive the final product and form an initial understanding of the materials and basic components of 3D paper sculpture. When given a faulty work, students could disassemble and recover the products to understand the design process of paper art by reverse thinking, and then identify the causes of the fault and fill out the disassembly chart. Next, students recovered the product and assessed the degree of recovery by themselves. They could also go through peer evaluation and analyze reasons for those who failed in the recovery step. Micro-innovation was then encouraged when students were asked to redesign their products. To be specific, students needed to determine a workable reconstruction scheme and draw out a target sketch or flowchart. During the redesign process, students could analyze deficiencies or new applications of the products under the guidance of the teacher, including changing the product's appearance, function, or performance. Finalyy, students were required to evaluate their works to see whether they had achieved the expected goals and compare them with original products through self-assessment, which was conducive to reflecting on their design intention.

The teaching procedures of the two pedagogies are listed in Figure 1.

Figure 1

The Teaching Procedures of FPP and REP in C-STEAM Education

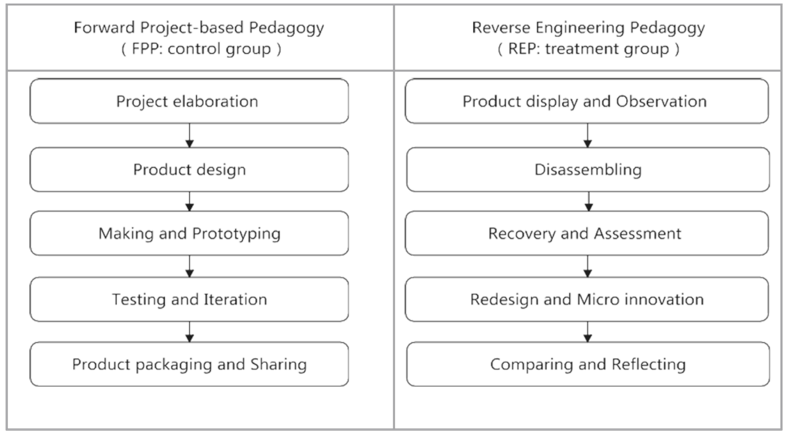
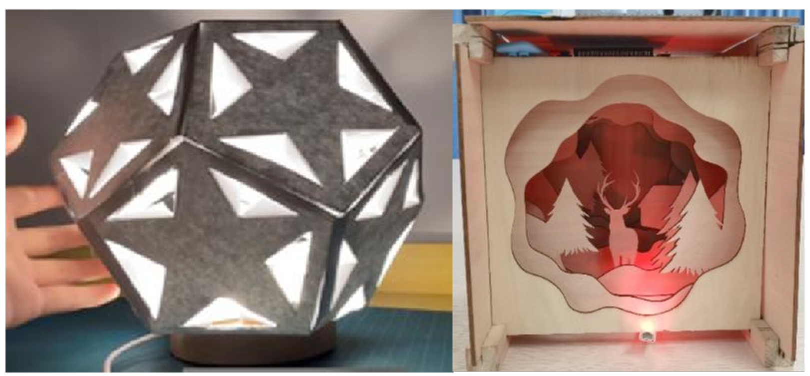


Figure 2

Examples of Students' Works



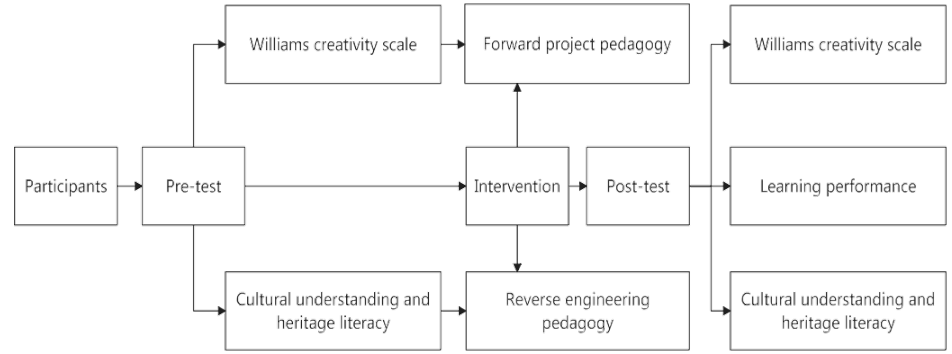
4.4. Research Process

Figure 3 shows the research process of this study. REP and FPP were adopted in the treatment group and the control group respectively, and the learning activities were observed throughout the whole class. A pre-test and post-test on students creativity and cultural heritage literacy were conducted before and after class. Besides, students learning performance was also tested in the

post-test.

Figure 3

Research Process in This Study



5. Result

5.1. Learning Performance

Table 1 shows the means and standard deviations of students learning performance in both the REP and FPP groups. As can be seen, students in the REP group performed significantly better than those in the FPP group, t (126) =-5.199, $p < .000$; the effect size (based on Cohen's d) was -0.417, which was consistent with H1.

Table 1

Means and Standard Deviations of Students' Learning Performance in the FPP and REP Groups

Scale	FPP		REP		t	p
	M	SD	M	SD		
Learning performance	26.94	5.374	32	5.64	-5.199**	.000

Note. * $p < 0.05$ ** $p < 0.01$

5.2. Cultural Heritage Competence

As shown in Table 2, there was no significant difference in the pre-test scores of the REP and FPP groups in either the total cultural heritage literacy score (t= .474, p = .636) or the three sub-scales: cultural understanding (t = -.325, p = .746), cultural recognition (t = 1.349, p = .180), and cultural practice (t = .469, p = .636), indicating basically equal starting levels of students in two groups. In the post-test, although there was no significant difference in the overall cultural heritage competence of the REG and FPP groups, students reported significantly higher degrees of cultural understanding in the REG group, t (126) = -2.917, p = .004; the effect size (based on Cohen's d) was .249. No significant difference was found in their cultural recognition (t = -1.194, p = .235) or their cultural practice (t = -.126, p = .900).

According to the results of the pre-test and post-test through a paired-sample t- test of the two groups at the cultural heritage literacy level, both FPP and REP had a significant impact on the overall cultural heritage competence. For the FPP group, t(126) = -16.227, p = .000, the effect size (based on Cohen's d) was .749; while for the REP group, t(126) = -15.977, p = .000, the effect size (based on Cohen's d) was .-792. Considering the sub-scale of the cultural heritage competence, in the control group, the mean value in each sub-dimension of the post-test was higher than that of the pre-test for cultural understanding (t = -14.334, p = .000), cultural recognition (t = -13.416, p = .000), and cultural practice (t = -12.172, p = .000). In the treatment group, the post-test was higher at a significant level than the pre-test scores for cultural understanding (t = -14.146, p = .000), cultural recognition (t = -13.348, p = .000), and cultural practice (t = -11.365, p = .000).

Table 2

Means and Standard Deviations of Students' Cultural Heritage Competence in the FPP and REP Groups

Scale		FPP		REP		t	p
		M	SD	M	SD		
Cultural understanding	Pre-test	11.91	4.777	12.19	5.023	-0.325	0.746
	Post-test	19.91	3.504	21.44	2.315	-2.917**	0.004
Cultural recognition	Pre-test	16.59	3.074	15.78	3.71	1.349	0.18
	Post-test	21.59	1.917	22.03	2.218	-1.194	0.235
Cultural practice	Pre-test	16.16	3.306	15.88	3.48	0.469	0.64
	Post-test	21.56	2.349	21.63	3.205	-0.126	0.9
Total	Pre-test	44.66	9.627	43.84	9.753	0.474	0.636
	Post-test	63.06	6.334	65.09	6.238	-1.828	0.07

Note. * p < 0.1; ** p < 0.01

5.3. Creativity

Table 3 shows the means and standard deviations of students' creativity and the paired-sample t-test results between REP and FPP. There was no significant difference in either overall creativity (t = .182, p = .856 > 0.05) or in the four sub-scales. On the pre-test for risk-taking (t=.820, p = .414 > 0.05), curiosity (t = -.164, p = .870>0.05), imagination (t=-.163, p= 871 > 0.05), and challenge (t=.384, p = .702 > 0.05), students in the two groups had the same baseline level.

No significant difference in the overall creativity scores (t = -1.061, p = .291 > 0.05) on the post-test between FPP and REP occurred. Concerning the four sub-dimensions, there was no significant difference in the challenge of creativity (t = .198, p = .844), but a significant difference was found in risk-taking: t (126) = 2.796l, p = 0.006, the effect size (based on Cohen's d) was

.240; curiosity: t (126) = 2.004, p = 0.047, the effect size (based on Cohen's d) was .175; and imagination: t (126) = -10.589, p = .000, the effect size (based on Cohen's d) was -.683.

Table 3

Paired-Samples t-Test Results for Creativity Literacy for the Pre-Test and Post-Test by Group

Scale		FPP		REP		t	p
		M	SD	M	SD		
Risk-taking	Pre-test	22.34	2.527	21.88	3.811	0.82	0.414
	Post-test	22.94	2.666	21.59	2.77	2.796**	0.006
Curiosity	Pre-test	29.31	3.541	29.44	4.957	-0.164	0.87
	Post-test	34.44	3.323	33.25	3.381	2.004*	0.047
Imagination	Pre-test	25.78	3.292	25.91	5.172	-0.163	0.871
	Post-test	25.56	2.322	29.81	2.217	-10.589***	0
Challenging	Pre-test	25.47	3.246	25.25	3.197	0.384	0.702
	Post-test	28.34	2.502	28.25	2.851	0.198	0.844
Total	Pre-test	102.91	10.78	102.47	15.966	0.182	0.856
	Post-test	111.28	8.575	112.91	8.755	-1.061	0.291

*Note.*** p < 0.01; *** p < 0.001

Through paired samples t-tests, the results implied the post-test scores of the two groups were higher at a significant level than the pre-test for overall creativity. Both FPP (t = -6.099, p = .000) and REP (t = -5.004, p = .000) had significant differences, which implied that students achieved improvement in creativity after they participated in the C-STEAM course. Concerning the improvement in creativity between the pre-test and post-test of the control group, there was a significant difference in curiosity of creativity (t = -9.609, p = .000) and challenge (t = -6.186, p = .000), but no significant difference in risk-taking (t = .437, p = .663 > .05) and imagination (t = .546, p = .587 > .05). In contrast, students in both groups had a significantly higher score on the post-test than on the pre-test for imagination (t = -4.735, p < 0.05), curiosity (t = -6.56, p < 0.05), and challenge (t = -5.267, p < 0.05), but no significant difference for risk-taking of creativity (t = 1.712, p > 0.05).

5.4. Correlation between Cultural Heritage Competence and Creativity

Table 4 presents the Pearson correlation coefficients (r2) of creativity and cultural heritage in the FPP and REP groups. There was no significant correlation between creativity and cultural heritage competence in the FPP group (r = .062, p = .629), while a strong correlation was found in the REP group (r = .677, p = .000). In particular, the subscale of Cultural Heritage (i.e., Cultural Practice & Cultural Recognition) have significant correlation with the subscale of Creativity (i.e., Risk-taking & Challenge). Cultural Practice was significantly related with Risk-taking (r = .612, p < .001) and Challenge (r = .747, p < 0.001), while Cultural Recognition was significantly related with risk-taking (r = .663, p < .001) and Challenge (r = .601, p < .001).

Table 4

Pearson Correlation Coefficients(r2) of Creativity and Cultural Heritage in the FPP and REP Groups

Intervention	N	Pearson Correlation between creativity and cultural heritage	Sig.(2-tailed)
FPP	64	0.062	0.629
REP	64	.677**	0

** Correlation is significant at the 0.01 level

6. Discussion

6.1. Learning Performance: Students in REP Performed SignificantlyBetter than Those in FPP

With respect to Hypothesis 1, REP outperformed FPP in learning performance, which was consistent with previous research by Zhong et al. (2020). In the REP group, students tackled problems by applying reverse thinking which could be more helpful for learning and managing the application of 3D formation paper sculpture. Specifically, students in the REP group could internalize relevant knowledge and skills as observed in the process of disassembling and recovering products, which could strengthen their understanding of 3D space and constructs.

6.2. Cultural heritage Competence: There is No Significant Difference in the Overall Level of Cultural Heritage Literacy between FPP and REP

As for Hypothesis 2, there was no significant difference between the REP and FPP groups in terms of overall cultural heritage, cultural recognition, and cultural practice; however, the REP group outperformed the FPP group in cultural understanding. This result might lie in the fact that cultural understanding of culture could be reinforced when students had a complete product in hand during learning, as they could have the opportunity to feel it and disassemble it, which would strengthen students' cultural perceptions and lead to deeper understanding.

A possible reason for the non-significant result on the cultural heritage scale might be that paper arts were attractive enough to raise students' learning interest so that they were all keen on the manufacturing operation and thus, enhanced their sense of cultural heritage. Most of the students perceived the glamor of paper sculpture and were aware of the necessity of protecting traditional cultures when they realized the gradually lost status of traditional paper carving skills. As reported by previous literature, STEAM education integrated with traditional culture could effectively tap learners' emotions and sense of value (Kim & Chae, 2016).

6.3. Creativity: Students in FPP Performed Significantly Better on Curiosity and Risk-Taking ThanThose in REP

In the case of Hypothesis 3, the results indicated that there was no significant difference in the promotion of risk-taking in creativity. Shellman and Ewert (2010) contended that the change of risk-taking was a long, gradual process, and students' risk-taking in this experiment had no evident changes due to the short period of this experiment. Nevertheless, the post-test of students in the FPP group for curiosity and risk-taking of creativity was better than that of the REP group. One factor might be that in the cultural creativity design teaching step, students could analyze the practical application of paper sculpture based on the exploration of the connotation and characteristics of the product, which contributed to stimulating students' creativity. As Kim and Chae's (2016) study, learning cultural heritage was helpful for developing students' creativity by exploring national cultural beauty. Students connected traditional culture and products by conducting function analysis and creative thinking in divergent thinking that could positively affect their curiosity (Vidler & Karan, 1975). While students could generate various ideas in the process, they might not determine which methods were suitable for tackling current problems. As Felder (1988) pointed out, people who were good at divergent thinking may produce various innovative ideas, while they might lack the ability to analyze and identify whether those ideas were suitable for solutions.

Concerning product creation, students in the REP group were given a complete product, which contributed to increasing their confidence. Consequently, they could perceive a relatively low potential risk to some extent, and so it could hardly enhance their ability to creative risk-taking. In contrast, in the FPP group, brainstorming generated in the cultural creativity and design steps encouraged students to think divergently, which was helpful for students to develop creativity and motivate them to take risks and seek new solutions (Harris & de Bruin, 2018). However, in this study, no significant difference was found in the imagination of students in the FPP group between the pre-test and post-test, which was contrary to the results above.

Data analysis of the post-test revealed that students in the REP group had a significantly higher degree of imagination than students in the FPP group. Reverse engineering pedagogy was more helpful for stimulating students' imagination and contributes to discovering problems and designing more innovative products. A possible reason to explain the result is presented as follows.

First, in the disassemble-recovery step and micro-innovative-redesign step, students analyzed and explored complete products, which contributed to creating a harmonious atmosphere within teams and stimulating imagination through the collision of ideas. The engineering design process under STEAM education had iteration and interactivity, and brainstorming, collaboration, and cognitive differences among members contributed to the generation of creativity (Shi et al., 2017). Moreover, Root-Bernstein (2015) suggested that arts and crafts training in STEAM education was significant for improving learners' various abilities, including dramatic vision and spatial imagination, hand-eye coordination and operability, ability to make and interpret models, as well as highly developed aesthetic and artistic acuity.

Second, students had apparent advantages in creative thinking and strategy in the micro-innovative and redesigned part because they could observe existing complete products. As Steven (2008) mentioned, when product dissection and reverse engineering were the guiding principles to establish improved design requirements and make suggestions for better designs, students tried to explore how the stapler worked in different ways. As a result, many creative ideas were produced for new staplers.

6.4. Creativity and Cultural Heritage Have a Strong Relationship in REP

The Pearson correlation coefficients indicated a strong relationship between creativity and cultural heritage in the REP group, while there was no evidence that cultural heritage was related to creativity in the FPP group. The most likely reason for these results might be the micro-innovation and redesign stage in the REP provided more challenge and risk and therefore, helped students explore cultural elements. According to Saad et al. (2012), achievements of students' creative originality came from producing numerous ideas that could then be explored and elaborated. Cultural cues in teamwork could shape creativity, especially in teamwork (Cox & Blake, 1991). Finke et al. (1996) suggested that generating more ideas was a key prerequisite for creative originality.

7. Conclusion

Adapting to the extending tendency of demand for innovative talents facing society today, forward-project pedagogy (FPP) and reverse engineering pedagogy (REP) of C-STEAM education were constructed in this study to satisfy the teaching purpose of enhancing creativity literacy and cultural understanding and heritage for students based on C-STEAM education. Specifically, the teacher first gave product elaboration in the FPP group, and then students designed culturally creative products and made prototypes according to their designs. After they finished the steps above, they needed to test and iterate until they finished the products. They also needed to package and share their products at the end of the course. In contrast, in the REP teaching process, students first observed the displayed incomplete products, and then disassembled them. Furthermore, they also needed to assess the products and recover them to better redesign and conduct micro innovations in the product. Last, students should reflect by comparing their works with those of other groups.

Both teaching models applied traditional paper sculpture culture as the subject of teaching content to carry out teaching activities, investigating the efficacy and difference of improvement in creativity and cultural competence for students between FFP and REP in the create-to-innovate C-STEAM course. It demonstrated that the two teaching methods could markedly improve students' creativity literacy and cultural competence. In fact, after a comparative study, we found that the teaching effect of the REP group in terms of creativity was generally better than that of the FPP group, especially in stimulating students ' imagination. This may be due to the fact that the teaching method of the REP group paid more attention to students active participation and practical operation and encourages students to explore and discover through practical operation, thus cultivating students imagination and creativity. In terms of curiosity and challenge of creativity, the FPP group performed slightly better, which may be related to the FPP group's more emphasis on systematic teaching and in-depth exploration of knowledge, so that students were better trained in curiosity and challenging spirit. With respect to cultural competence, the FPP and the REP could promote the cultivation of cultural recognition, cultural understanding, and cultural practice regarding paper sculpture culture, with no significant difference between the two groups. This showed that both teaching methods could effectively promote the cultivation of students cultural competence. The reason may be that although the two teaching methods were different, they both focused on the core goal of cultivating cultural competence, so they achieved the same effect at this point.

Compared with the FPP group, students in the REP had a significantly higher degree of compatibility of imagination, cultural understanding, and learning performance. Teaching methods constructed based on reverse engineering theory could be more helpful for developing students' innovative thinking to improve the performance of products. The most probable reason for this might be that the REP is based on the concept of reverse thinking that encouraged students to cooperate in groups, which helped trigger ideas (Elizalde et al., 2008). In the FPP group, students started from scratch and managed under the guidance of the teacher's explanation to make paper sculptures, while in the REP group, students began with a complete product and experienced disassembly and recovery of paper sculptures, micro innovation, and redesign, which contributed to the harmonious cooperation among students. This made it easier to generate the collision of ideas in discussion and communication in the groups.

8. Implications

This study conducted a contrast experiment to examine the effect of REP on cultivating students' cultural heritage literacy and creativity. It provides a typical case for the future development of C-STEAM education, and to enrich educational research on this pedagogy to enrich the theory and practice of STEAM education, as well as to support the cultivation of students innovative thinking and creativity.

Results of this study showed that both FPP and REP could gradually guide students to experience cultural connotation and artistic characteristics in a reasonable way, constructing cultural recognition of paper sculpture during the process of teaching, conducting creational design and product development for traditional culture based on the cultural connotations and artistic characteristics. They helped students creative thinking skills to develop while promoting cultural heritage competence.

It also highlights some future research directions for follow-up studies. On one hand, it is suggested to tap into and develop the students' sustainable emotions and thinking skills for the purpose of inheriting traditional culture. In this study, both FPP and REP contributed to improving students' cultural heritage literacy. Students' interest and understanding of traditional culture, and consciousness of cultural protection were enhanced. However, as maintained by Shellman and Ewert (2010), change of adventure was a long-term process, so this project should be conducted on a long-term teaching scale rather than as a transient course experiment. Therefore, it should be beneficial to conduct a longitudinal study targeting the cultivation of student emotions and thinking skills in the long run.

On the other hand, teachers professional attainments in implementing REP should be paid further attention to. In contrast to FPP, reverse engineering pedagogy places higher-level demand on teachers in terms of time management of the course and preparation of instructional resources. Specifically, students spent longer on the product disassembly and correction and micro-innovation and redesign segments than expected, so it was necessary for teachers to become more sensitive to time management in each part of teaching and urge students in the creative process to enhance classroom efficiency. Moreover, providing proper curriculum instruction is especially important; teachers need to clearly understand their roles in the C-STEAM course as instructional designers, activity organizers, lecturers, and artifact demonstrators. It also requires teachers to understand both the cultural knowledge and the other multidisciplinary content knowledge, and guide students to utilize interdisciplinary knowledge to solve problems.

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Data Availability Statement

The data used in this study are available upon request. Please contact the corresponding author or the data repository to request access to the data.

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Conflict Of Interest Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Approval Statement

This study was approved by the Institutional Review Board (IRB) of our institution. The IRB reviewed and approved the study protocol, including the informed consent process, data collection methods, and ethical considerations.

Participant Consent Statement

Before participating in this study, each participant was provided with a detailed information sheet that explained the purpose, methods, potential risks, and benefits of the study.

After reading the information sheet, each participant was asked to provide written consent by signing a consent form. The consent form explicitly stated that participation was voluntary, that the participant could withdraw from the study at any time, and that the data would be used only for the purposes of the study and would be anonymized if published.

By signing the consent form, the participants agreed to participate in the study and to allow the research team to collect, analyze, and use their data for the purposes of the study. The research team will ensure that the participants' privacy is protected and that their data will be used only for the purposes of this study. Permission to Reproduce Material from Other Sources

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